International Journal of Electrical and Computer Engineering (IJECE)
Vol. 12, No. 3, June 2022, pp. 2432~2440
ISSN: 2088-8708, DOI: 10.11591/ijece.v12i3.pp2432-2440

A multipart distributed modelling approach for an automated protection system in open-air cloth drying

Moses Oluwafemi Onibonoje, Adedayo Olukayode Ojo
Department of Electrical/Electronics and Computer Engineering, Afe Babalola University, Ado Ekiti, Nigeria

Article Info

Article history:

Received Feb 4, 2021
Revised Aug 30, 2021
Accepted Oct 22, 2021

Keywords:

Automated system
Drenched clothes
Modelling
Protection system
Wireless sensor

ABSTRACT

There are different methods of drying wet clothes but drying with direct sunlight is considered the best suited for the preservation of the quality and usability of the cloths. However, sudden rainfall during the drying period constitutes a major drawback of the method. This returns the cloths to a drenched state as it is practically impossible to watch the clothes dry off after washing. This paper has proposed a model for an automated system for controlled open-air fabric drying by detecting the rain and moisture status of the cloths in real-time, and capable of shielding them to safety from the rainfall and excess sun. The modelled part considers the sensing model, drying model, control model, and their validation. The implementation and evaluation stage relate the result of the validated results to the developed prototypes. The simulated results in the sensing unit indicate above 87.5% agreements with the analytical results, and the controller simulated result provides a relatively small overshoot and faster dynamic response. Manufacturers of hanger systems for cloth drying have a basis for the design and implementation of their products in the paper.

Corresponding Author:

Moses Oluwafemi Onibonoje
Department of Electrical/Electronics and Computer Engineering, Afe Babalola University
Ado-Ekiti, Nigeria
Email: onibonojemo@abuad.edu.ng

1. INTRODUCTION

One of the basic needs for human survival is clothing as human beings are inherently shy mammals, there is always a need to cover themselves and shield their nakedness. Apart from clothes aiding in covering the nakedness of man, they also support beautification and protection from harsh weather conditions on humans. Hence, clothing is very important to man, as different clothes are used for different reasons, and to different places. Majority of clothes are been purposed for re-use, thereby making laundry and dry-cleaning of cloths a necessary part of human endeavor. Sun-drying is often the most common form of cloth drying. However, rain and the accompanying wind remain major factors that alter a seamless drying process for drenched fabrics [1].

Automating the laundry process is always very difficult. The different steps towards ensuring that the quality and safety of the cloths are intact require precise measures and implementation. However, cloths are objects of high deformation feature with physical properties which are challenging to handle by systems acting autonomously. Cloths are designed with flexible materials which are difficult to handle with a high level of precision or repetitiveness-a factor needed to be present in automated systems. Therefore, the existing possible automatic and autonomous systems are limited in capacity to handle the special steps for cloth laundry-wash, dry, and fold [2], [3]. A feasible approach is needed to manipulate the chemistry of cloth laundry and automation by understanding the clothing configuration and the estimation of any process that can alter the configuration. In the laundry process, as shown in Figure 1, cloth washing automation has been adequately researched into, while the drying and folding stages require more works [4]. The various other processes adjoining the laundry system have also been dealt with in implementations. Laundry processes are carried out in the store each day, with activities including taking receipt of clothes, washing, drying and ironing. In addition to managing these activities, an intelligent laundry outlet can manage client data, helps customers to locate their clothes within the store, indicates which processes have been completed, and shows the appropriate time to revisit the store for a pick-up of the dry-cleaned clothes [5]. Many workers in corporate organizations hardly have enough time to manually execute their hitherto domestic routines. They often execute their cloth washing in the machines and suspend or spread them in the open space for sun-drying during the day. However, the relatively dried clothes on the suspension are easily drenched up again by the day rain when the people are already at work. The drying and folding stages of a laundry process demand a comprehensive approach to detect the environmental factors such as rain and sunlight level, spread the cloths for drying when the necessary condition is met, and then fold the cloths as required. The drying stage also required a control measure to fold the cloth when it is about to rain and unfold the cloths when the rain stops. The automation of these stages is important to help people accomplish their routine in the face of their conflicting day-to-day schedules. Cloth drying during a laundry exercise has been an important research area in recent times. For the cloth-drying being implemented with the sunlight, the need for adequate automatic measures of preventing the cloth from any further drenching in case of rain is now rife [4], [6].

Modelling a system with multi-part constituents requires definite methods with feasible results. Hammerstein systems in a continuous mode can be modelled using the hybrid metaheuristic algorithm. The parameters of the linear and nonlinear subsystems within such systems can be identified using the hybrid approach [7]. The cloth washing real systems can be modelled against such Hammerstein model with continuous-time transfer function, based on using the Grey Wolf Optimizer method to tune both the coefficients of the nonlinear and transfer functions of the model. The identification of the liquid sloth behavior framework can be incorporated into minimizing the error between the identified output and the main experimental output [8]. The control mechanism of the drying and protection system can be considered using the previous works relative to parametric estimation of modelled multiple-input-multiple-output systems and mobile robots [9], [10].

The synergistic relationship between robotics and wireless sensor technologies have introduced the possibility of a distributed and automated monitoring and control approach into various domestic and commercial processes [11], [12]. Currently, robots appear to emulate human intelligence while performing even additional tasks. Therefore, more robots and machines are gradually replacing humans in hitherto reserved tasks and functions. The two technologies are suitable for the laundry drying process, with sensors monitoring the status of the cloths and the weather, while the machine performs the functions on the folding and unfolding of the cloths [2], [13]–[15]. Meanwhile, the real-world problems can be represented by mathematical models with the solutions simulated, analyzed, and validated to predict the representative behavior of such systems applicable to the solution. The different models that are related to the detailed aspects of sensor technology and robotics have been highlighted in [16], [17]. The research work of [18] established that ultrasonic vibrations constitutes the tools for atomization of liquids to get fine mist, and provides promising solutions for efficient drying technology of clothes. This had been demonstrated by researchers in 'Oak Ridge National Laboratory' with prototypes being developed to apply the scientific principles of ultrasonic drying. The principle is built on the mechanical correlation between wet fabrics and mesh-based piezoelectric transducers. The experimentally validated model proposed by the author bridged the vibrations by the transducer with the critical acceleration required for cloth drying to ensue. This paper proposes a model and implementation criteria for a distributed and automated approach to a controlled fabric drying, folding and unfolding, based on the sensed parameters and preset references. The study has bridged a researched gap in employing an integrated modelling approach to the constituent parts of the open-air drying system. It proposed models with coverage of the condition monitoring of the fabrics and the control of the drying process.

2. METHOD

A sequenced approach is adopted in this study namely: modelling, validation and implementation. The methodology is based on the system identification and modelling of the respective component units of a standard automated open-air drying system, as highlighted here. In the motor controlling unit of the system, to provide the cover when the preset condition of rain detection and/or fully dried cloths is detected, the design was made using MATLAB Simulink with controller coefficients fully adjusted to capture the transceiver data as shown in Figure 1.

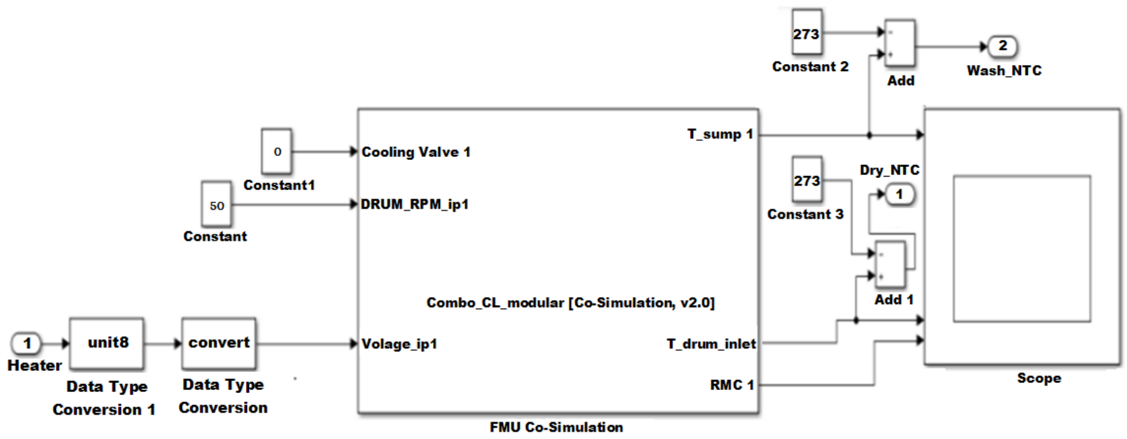


Figure 1. The MATLAB Simulink model page

2.1. System identification

A multi-part sensing-drying-control (SDC) model is adopted. The modelled part considers the sensing model, drying model, control model for folding and unfolding, and the validation. The implementation and evaluation stage relates the result of the validated results to the developed prototypes. The distributed sensing and drying units have their inputs and outputs measured in the time domain, and modellied by using the discrete sampled data dynamic representation, while the control unit flapped the drying stage double actuating inputs being measured in the frequency domain and being modelled into two separate and unique single-input-single-output systems (SISO). The model structure and the estimation method adopted for the adjustable parameters for each unit model structure are detailed in the adjoining subsections, while the step-by-step approach to the process is as shown in Figure 2.

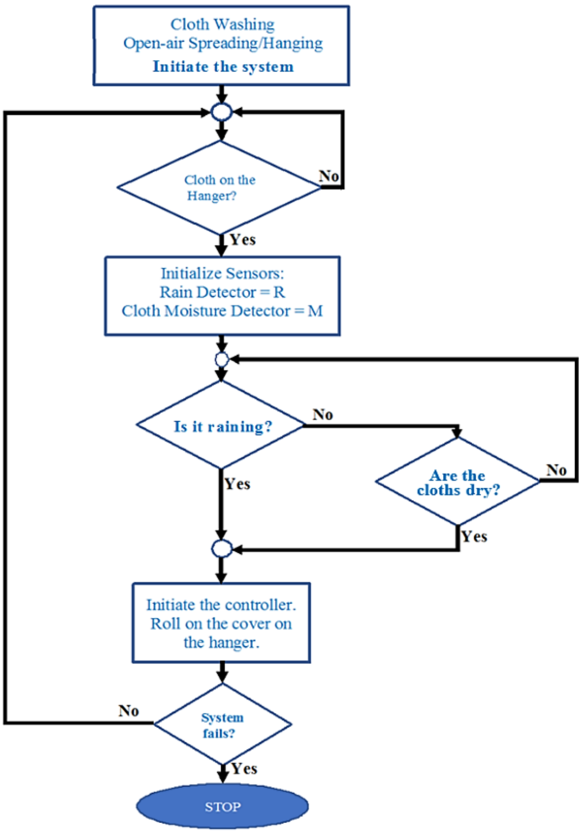


Figure 2. A step-by-step architecture of the system

2.2. Sensing model

The system sensing unit is modelled using the adaptive method as put forward in 2001 [19] for the two inputs sensors in each node as illustrated in Figure 3. The integrated approach which is supported in the study [20] is used to incorporate the distributed nodes for monitoring the two basic factors within a defined controlled area of cloths spread or hanging: the weather condition and the drying status of the cloths. The output of each sensing node presents a discrete function that has the transfer function of the described matrix, the state equation for the memory of the node which is an integrator, and the output equation in (1) to (3) respectively. The discrete sampled data representation can be described by the matrix function in (4), the discrete model is as stated in (5), while the model output differential equation is highlighted in (6).

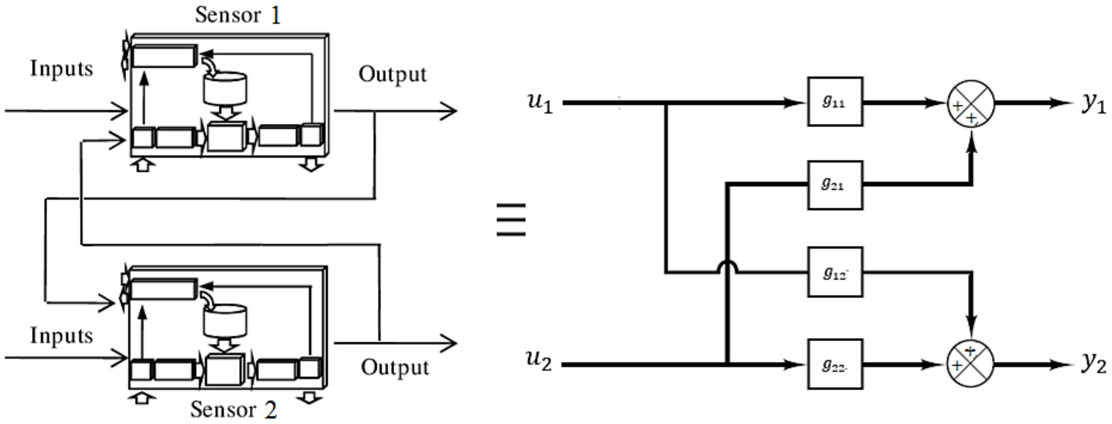


Figure 3. The p-structure for a two-sensor node system

$$G(s) = \begin{bmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{bmatrix} \tag{1}$$

$$\dot{x} = Ax + Bu \tag{2}$$

$$y = Cx + Du \tag{3}$$

$$G(z^{-1}) = A^{-1}(z^{-1})B(z^{-1}) \tag{4}$$

$$A(z^{-1}) = \begin{bmatrix} 1 + a_1 z^{-1} + a_2 z^{-2} & a_3 z^{-1} + a_4 z^{-2} \\ a_5 z^{-1} + a_6 z^{-2} & 1 + a_7 z^{-1} + a_8 z^{-2} \end{bmatrix}$$
$$B(z^{-1}) = \begin{bmatrix} b_1 z^{-1} + b_2 z^{-2} & b_3 z^{-1} + b_4 z^{-2} \\ b_5 z^{-1} + b_6 z^{-2} & b_7 z^{-1} + b_8 z^{-2} \end{bmatrix} \tag{5}$$

$$y_1(k) = -c_1 y_1(k-1) - c_2 y_1(k-2) - c_3 y_2(k-1) - c_4 y_2(k-2)$$
$$+d_1 u_1(k-1) + d_2 u_1(k-2) + d_3 u_2(k-1) + d_4 u_2(k-2)$$
$$y_2(k) = -c_5 y_1(k-1) - c_6 y_1(k-2) - c_7 y_2(k-1) - c_8 y_2(k-2)$$
$$+d_5 u_1(k-1) + d_6 u_1(k-2) + d_7 u_2(k-1) + d_8 u_2(k-2) \tag{6}$$

The homogenous sensing nodes are integrated into a networked single system with the control node, with the respective parameters from the individual node being processed for decision making. The iterated data of the networked sensing nodes is as represented in (7). Each node i at $t \geq 0$ is described by the two parameters of interest: the weather condition, y_1 and the drying status of the cloths, y_2. A trilateration estimation method described in the study [21] is adopted to ensure that each anchor node stores its position coordinates relative to data reception from the targeted node, and use the estimated distance in-between estimate the adjustable humiture parameter for condition monitoring. The state equation of the sensing unit becomes (7), and the output equation becomes (8). With the application of Taylor's series approximation, the sensing node model presents a form as stated in (9), (10).

$$\dot{x}(t) = f(x, y_{1,i}, y_{2,i}, t) \tag{7}$$

$$y(t) = g(x, y_{1,i}, y_{2,i}, t) \quad (8)$$

$$\Delta y = y(t) - g(y_{1,i}, y_{2,i}) \quad (9)$$

$$\Delta y = \frac{dg(y_{1,i}, y_{2,i})}{dy_{1,i}} \Delta y_{1,i} + \frac{dg(y_{1,i}, y_{2,i})}{dy_{2,i}} \Delta y_{2,i} \quad (10)$$

2.3. Drying model

The model for the drying rate is developed to consist of a primary non-linear region based on ionization and then followed with a region of linear thermal wet loss. There exists an imbalance between the present moisture in the cloths and the surrounding air. Meanwhile, there is a higher concentration of the water vapor at the surface of the cloth than the surrounding air, making diffusion to occur from the cloth to the surrounding. The relationship among the mass of the dry cloth, m_{dc}, the mass of the water moisture present in the cloths, m_v, and the concentration of the moisture, M_c is defined by (11), while Fick's law relates diffusive flux of vapour between the cloth and the surrounding by the rate of change of the moisture concentration as shown in (12). The air humidity ratio can be correlated with the air moisture concentration by using the ideal gas state equation as stated in (13):

$$M_c = \frac{m_v}{m_{dc}} \quad (11)$$

$$D_R = \frac{dM_c}{dt} = t_m(M_a - M_c) \quad (12)$$

$$M_a = \left(\frac{P_a V_a / c T_a}{m_{dc}}\right) H_{abs} \quad (13)$$

where D_R is the drying rate, t_m is the coefficient of mass transport as a strong function of the airspeed, and M_a is the concentration of moisture in the air. V_a represents the effective dry air volume, P_a is the dry air pressure, c represents the dry air gas constant. H_{abs} represents the absolute air humidity, and T_a represents the temperature of the air.

The rate of change of the moisture concentration at the surface of the cloth is dependent upon the heat index of the air surrounding the cloth, as a function of both the humidity ratio and temperature of the air. The assumption is that the water moisture in the cloth is uniform due to the small volume ratio to the surface of the cloth. A higher diffusive flux depends on a higher air temperature and lowers air humidity ratio. Meanwhile, the coefficient of mass transport is directly proportional to airspeed. The quantum of effects contributed by each factor: air temperature, the humidity of vapor in the air, and the coefficient of mass transport, to the drying factors, are validated in the performance indices of the cloth dryer as established by [22]–[24]. The drying kinetics is derived from the determination of the moisture content in the cloths on a dry basis using (14) and (15):

$$\%M(d) = \left(\frac{W_w - W_d}{W_d}\right) \times 100 \quad (14)$$

$$MR = \frac{M(d)_t}{M(d)_0} \quad (15)$$

where $M(d)$ represents the moisture content on a dry basis, W_w is the weight of the wet cloth, and W_d is the weight of the dried cloth. MR is the moisture ratio. $M(d)_0$ is the initial moisture content of the cloth, and $M(d)_t$ is the dry-basis moisture content of the cloth after a time (t).

2.4. Control model

A well-known active-reactive power theory called the P-Q method is employed in designing the two-stage actuating condition of the cloth drying process for the dual-input-single-output scenario. Recent studies [25], [26] have supported the use of the method for modelling time-invariant control scenarios. The method transforms the problem for the double actuating inputs into two separate and unique single-input-single-output systems (SISO) as shown in Figure 4. In the SISO system has the compensators, $k_1'(s)$ and $k_2'(s)$ selected simultaneously to arrive at a transfer function, $G'(s)$ expressed in (16) and the characteristic equation expressed in (17). The relative contribution of each path output is described over frequency, and interference that can result from the phase lag in the paths is reduced to a minimum.

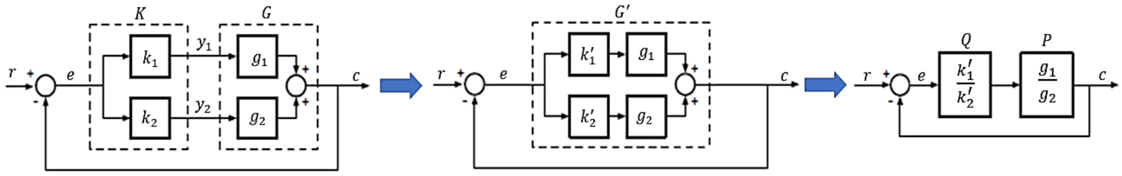


Figure 4. The P-Q method transforming the double-input to a single-input with one controllable output

$$G'(s) = k_1'(s)g_1(s) + k_2'(s)\, g_2(s) = 0 \tag{16}$$

$$1 + \frac{k_1'(s)g_1(s)}{k_2'(s)\, g_2(s)} = 1 + P(s)Q(s) = 0` \tag{17}$$

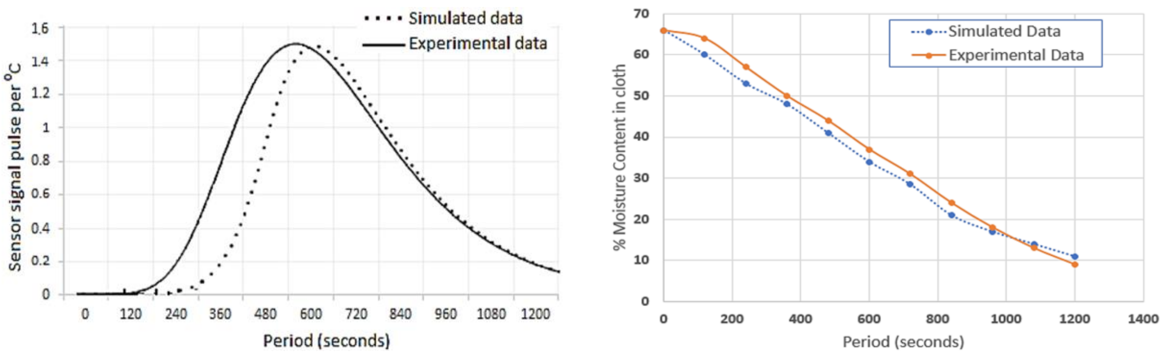
where $P = \frac{g_1}{g_2}$ and $Q = \frac{k_1'}{k_2'}$ represent the plant and controller ratio respectively. Meanwhile, by allocating the output relative to frequency, the resulting equations are as shown in (18) and (19). Therefore, the compensator for the system is designed as a discrete value $k_0(z)$, while the performance function can be determined on a linear Bode plot tool.

$$P(e^{i\omega t}) = \frac{g_1(e^{i\omega t})}{g_2(e^{i\omega t})} \tag{18}$$

$$G'(e^{i\omega t}) = k_1(e^{i\omega t})g_1(e^{i\omega t}) + k_2(e^{i\omega t})\, g_2(e^{i\omega t}) \tag{19}$$

3. RESULTS AND DISCUSSION

The models developed for the three sections were simulated and the results evaluated for validation. The sensor model was simulated using the MATLAB and the results compared with a projected moisture-based performance. The signal response to the unit change in temperature of the sensing unit for 20 minutes was evaluated as shown in Figure 5(a), while the drying rate across a range of temperature within the period was also simulated and evaluated as shown in Figure 5(b). The sensors were tested with a dried-up cloth at 94 ^{0}C, and when the cloth was soaked with water to about 10% moisture content at almost ±1% error tolerance. The simulated results in both cases indicate above 87.5% agreements with the analytical results. It is observed that the model is indicative of no thermal bridging in the measuring sensor probes, a very useful condition for cloth drying monitoring.



(a) (b)

Figure 5. Simulated outputs (a) sensor analytical and simulated outputs pulse to temperature over a period and (b) drying response against time for the simulated model and the experimental process

By setting the value of a PI controller gains at $k_p = 10$ and $k_i = 39$ and that of the proposed model at $k_1' = 0.51$, $k_2' = 27$ and $k_0 = 17.2$ in the optimization process, Figure 6 shows the unit step response of the regulated DC motor speed as controlled by a standard PI controller and the proposed P-Q model. It is observed that the model provides a relatively small overshoot and faster dynamic response.

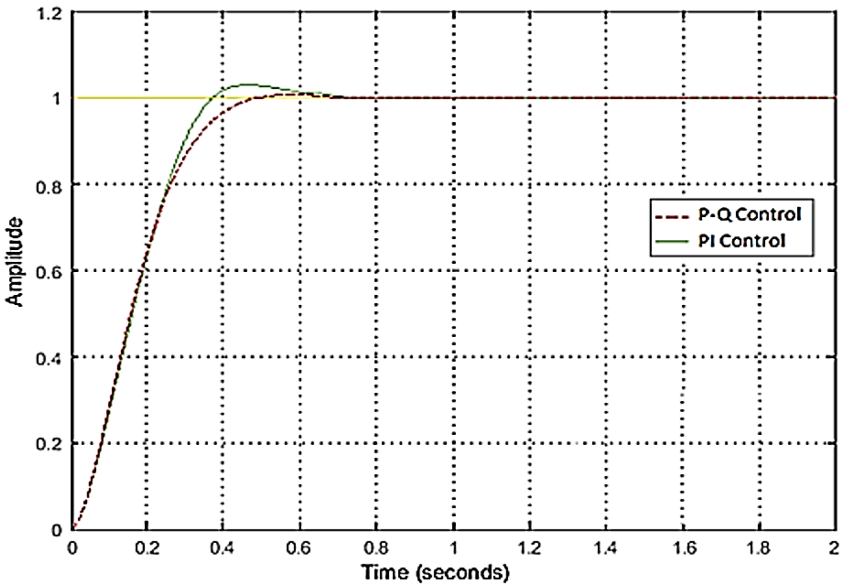
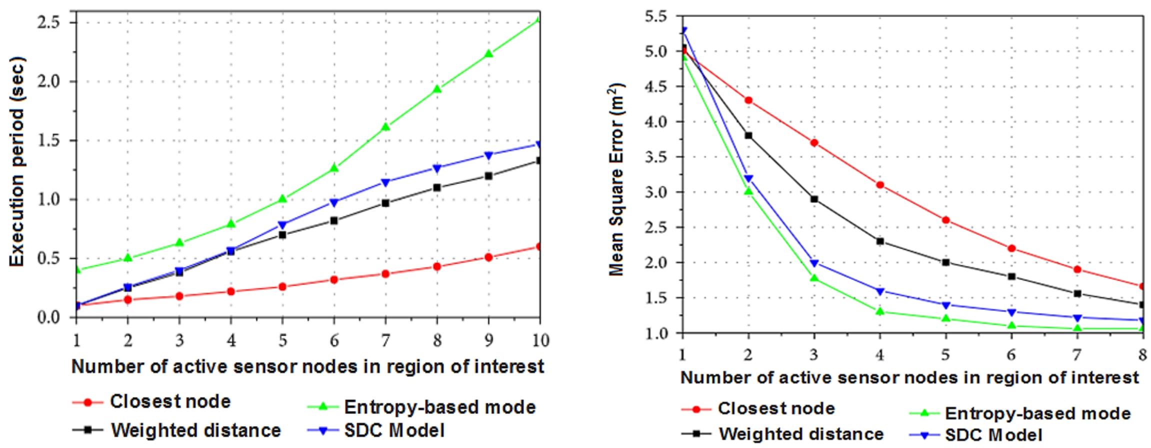


Figure 6. Simulated result of the PI and PQ model methods

3.1. Performance evaluation

The performance of the sensing unit model was evaluated by simulating a network of 10 sensors randomly. These were compared with the entropy-based selection criteria in which each node was selected based on weighted or closest distance, and information utility in terms of mean square errors and execution time as shown in Figures 7(a) and 7(b). The results indicate about 83.2% accuracy on execution time, and 89.4% against the mean square error (MSE), using an average basis on other criteria employed.



(a) (b)

Figure 7. Evaluation result of the SDC sensing unit using (a) execution time basis and (b) mean square error basis

4. CONCLUSION

A modelling approach to protecting the open-air drying cloths has been proposed in this paper. The sensing unit, drying process and the applicable controller were modelled by integrating the dual-input-single-output and the P-Q methods and the simulated results by MATLAB Simulink were evaluated. The simulated results in both the sensing and controller units indicate very good performance evaluation. The magnitude of the model gains determines the comparative contributions of the parallel pairs of each unit as a function of frequency. Manufacturers of sensors and controllers mostly rely on models to design the various systems to solve targeted problems. Therefore, complete system evaluation is always necessary for sensors and controllers to ensure interactive mode implementation, even when real-time simulators are applied on isolated device units. This enables performance evaluation to be validated against a wide spectrum and ensure the minimization of most the assumptions. Hence, future research work.

REFERENCES

[1] O. Valkó *et al.*, "Laundry washing increases dispersal efficiency of cloth-dispersed propagules," *NeoBiota*, vol. 61, pp. 1–16, Oct. 2020, doi: 10.3897/neobiota.61.53730.

[2] M. O. Onibonoje and N. Nwulu, "Synergistic technologies for precision agriculture," *Artificial Intelligence and IoT-Based Technologies for Sustainable Farming and Smart Agriculture*, pp. 123–139, 2021, doi: 10.4018/978-1-7998-1722-2.ch008.

[3] C. Bersch, B. Pitzer, and S. Kammel, "Bimanual robotic cloth manipulation for laundry folding," in *2011 IEEE/RSJ International Conference on Intelligent Robots and Systems*, Sep. 2011, pp. 1413–1419, doi: 10.1109/IROS.2011.6095109.

[4] B. Willimon, S. Birchfield, and I. Walker, "Model for unfolding laundry using interactive perception," in *2011 IEEE/RSJ International Conference on Intelligent Robots and Systems*, Sep. 2011, pp. 4871–4876, doi: 10.1109/IROS.2011.6095066.

[5] N. Truong Van, S. Joon Lee, C. Won Lee, K. Hwan Eom, and K. Kwon Jung, "An implementation of laundry management system based on RFID hanger and wireless sensor network," in *2012 Fourth International Conference on Ubiquitous and Future Networks (ICUFN)*, Jul. 2012, pp. 490–493, doi: 10.1109/ICUFN.2012.6261758.

[6] B. S. Sathish Kumar, M. Selvaganapathy, I. S. Siva Siddharth, and G. Kumaresan, "Design and experimental study on automatic cloth retrieval and drying system," *International Journal of Advance Research, Ideas and Innovations in Technology*, vol. 3, no. 2, pp. 49–57, 2017.

[7] J. J. Jui and M. A. Ahmad, "A hybrid metaheuristic algorithm for identification of continuous-time Hammerstein systems," *Applied Mathematical Modelling*, vol. 95, pp. 339–360, Jul. 2021, doi: 10.1016/j.apm.2021.01.023.

[8] M. A. Ahmad, Z. Musa, M. H. Suid, and M. Z. M. Tumari, "Grey wolf optimizer for identification of liquid slosh behavior using continuous-time hammerstein model," *Bulletin of Electrical Engineering and Informatics (BEEI)*, vol. 9, no. 2, pp. 542–549, Apr. 2020, doi: 10.11591/eei.v9i2.2074.

[9] B. Raafiu and P. A. Darwito, "Identification of four wheel mobile robot based on parametric modelling," in *2018 International Seminar on Intelligent Technology and Its Applications (ISITIA)*, Aug. 2018, pp. 397–401, doi: 10.1109/ISITIA.2018.8710761.

[10] A. V. Joseph and S. P. Arjunan, "Comparative analysis of parameter estimation techniques for modelling a twin rotor MIMO system," in *2019 3rd International Conference on Recent Developments in Control, Automation & Power Engineering (RDCAPE)*, Oct. 2019, pp. 704–709, doi: 10.1109/RDCAPE47089.2019.8979083.

[11] K. S. Alli *et al.*, "Development of an arduino-based obstacle avoidance robotic system for an unmanned vehicle," *ARPN Journal of Engineering and Applied Sciences*, vol. 13, no. 3, pp. 886–892, 2018.

[12] M. O. Onibonoje, N. I. Nwulu, and P. N. Bokoro, "A wireless sensor network system for monitoring environmental factors affecting bulk grains storability," *Journal of Food Process Engineering*, vol. 42, no. 7, Nov. 2019, doi: 10.1111/jfpe.13256.

[13] A. Milella, G. Reina, and M. Nielsen, "A multi-sensor robotic platform for ground mapping and estimation beyond the visible spectrum," *Precision Agriculture*, vol. 20, no. 2, pp. 423–444, Apr. 2019, doi: 10.1007/s11119-018-9605-2.

[14] N. L. Diaz, J. G. Guarnizo, M. Mellado, J. C. Vasquez, and J. M. Guerrero, "A robot-soccer-coordination inspired control architecture applied to Islanded microgrids," *IEEE Transactions on Power Electronics*, vol. 32, no. 4, pp. 2728–2742, Apr. 2017, doi: 10.1109/TPEL.2016.2572262.

[15] P. Jiménez and C. Torras, "Perception of cloth in assistive robotic manipulation tasks," *Natural Computing*, vol. 19, no. 2, pp. 409–431, Jun. 2020, doi: 10.1007/s11047-020-09784-5.

[16] O. Tymchenko, K. Zelyanovsky Michałand Szturo, and Oleksandr O. Tymchenko, "Mathematical models for specialized and sensory networks of wireless access," *Technical Sciences*, vol. 19, no. 2, pp. 129–138, 2016.

[17] M. O. Onibonoje, "Modeling and analysis of modulation schemes on antenna space blocks time code," *International Journal of Scientific {\&} Technology Research*, vol. 8, no. 9, pp. 2246–2251, 2019.

[18] E. D. Dupuis, A. M. Momen, V. K. Patel, and S. Shahab, "Electroelastic investigation of drying rate in the direct contact ultrasonic fabric dewatering process," *Applied Energy*, vol. 235, pp. 451–462, Feb. 2019, doi: 10.1016/j.apenergy.2018.10.100.

[19] M. KubalCik and V. Bobal, "Adaptive control of a two input-two output system," in *IFAC Adaptation and Learning in Control and Signal Processing*, 2001, pp. 163–168.

[20] M. Oluwafemi Onibonoje, A. Olukayode Ojo, and T. Emmanuel Fabunmi, "A distributed wireless heat monitoring system for early-fire detection and prevention," *Universal Journal of Electrical and Electronic Engineering*, vol. 6, no. 4, pp. 282–290, Oct. 2019, doi: 10.13189/ujeee.2019.060410.

[21] Y. Miao, H. Wu, and L. Zhang, "The accurate location estimation of sensor node using received signal strength measurements in large-scale farmland," *Journal of Sensors*, vol. 2018, 2018.

[22] N. M. Ortiz-Rodríguez, J. F. Marín-Camacho, A. L.- González, and O. García-Valladares, "Drying kinetics of natural rubber sheets under two solar thermal drying systems," *Renewable Energy*, vol. 165, pp. 438–454, Mar. 2021, doi: 10.1016/j.renene.2020.11.035.

[23] A. Chailoet, T. Kliniam, R. Muangpisan, P. Kiatkungwankai, and T. Leephakpreeda, "Analytical and experimental studies of rapid cloth drying for technological innovation," in *MATEC Web of Conferences*, 2018, vol. 220, p. 4007.

[24] D. M. Ramirez-Gutierrez, K. E. Ileleji, and A. J. Deering, "Evaluation of novel portable passive and cabinet solar dryers in sun drying of mint leaves under Indiana weather conditions," *Transactions of the ASABE*, vol. 64, no. 3, pp. 1083–1094, 2021, doi: 10.13031/trans.14208.

[25] S. J. Schroeck, W. C. Messner, and R. J. McNab, "On compensator design for linear time-invariant dual-input single-output systems," *IEEE/ASME Transactions On Mechatronics*, vol. 6, no. 1, pp. 50–57, 2001.

[26] R. R. Holly and C. M. William, "Controller design for two stage actuators using the PQ method and the sbode plot," *Asia-Pacific Magnetic Recording Conferences*, 2000.

BIOGRAPHIES OF AUTHORS

Moses Oluwafemi Onibonoje is an Associate Professor in the Department of Electrical/Electronics and Computer Engineering at Afe Babalola University Ado-Ekiti (ABUAD), Nigeria. He specializes in Control and Instrumentation Engineering. His research areas include Wireless Sensor Networks, Distributed Systems, Wireless Instrumentations, Optimization Methods, and Agro-Electro Instrumentations. Dr. Onibonoje holds a Ph.D. in Electronic and Electrical Engineering from Obafemi Awolowo University, Ile-Ife, Nigeria. He is COREN Registered and a Corporate Member of the Nigerian Society of Engineers. Email: onibonojemo@abuad.edu.ng.

Adedayo Olukayode Ojo graduated from the Department of Electronic and Electrical Engineering in Ladoke Akintola University of Technology (LAUTECH) Nigeria in 2008 where he received his B. Tech degree with honours. He obtained his Msc degree in Microelectronics from Universiti Putra Malaysia (UPM) in 2014. He is currently a lecturer at the department of Electronic Electrical and Computer Engineering, Afe Babalola University Ado Ekiti, Ekiti State Nigeria. He is currently pursuing a PhD degree at the Department of Electronic Electrical Engineering, Ekiti State University, Nigeria. His research interests include communication systems, microelectronics, soft computing and intelligent systems. Email: ojoao@abuad.edu.ng.